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Title: Prevention, Monitoring and Response Strategies regarding Alien Invasions of Continental Antarctica: Their Context, Past Experience, Current Procedures and Recommendations for the Future

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Abstract/executive summary (ca. 200 words):

Preserving the native fauna and flora of Antarctica is a legal obligation on Antarctic Treaty signatory countries by the Madrid Protocol. This report addresses threats to the native biota that alien species present, particularly those with invasive characteristics. Historically, protection against alien species' invasion has been achieved through increasingly rigorous and effective quarantine inspection procedures of people and cargo leaving for the territory. In recent years, monitoring has been recognised as important for identifying those species which slip through inspections, and there is increasing recognition of the need to formulate effective and unified response plans.

This essay discusses these issues generally in the context of continental Antarctica, and goes on to relate them to specific needs identified as relating to New Zealand's Scott Base. Invasive species from viruses, bacteria and algae to plants and small animals are considered. Recommendations are made for improvements in prevention, monitoring and response to preserve the Ross Island region in particular. These include suggestions for improving the Base's reporting system for insect incursions, for effective monitoring of plants in the base vicinity and beyond, and the need for a full-time biosecurity post. Key issues are identified that may form the basis of a comprehensive response plan, including the methods by which alien species can be reliably identified, how they should be

dealt with, and whether herbicides and pesticides might be acceptable solutions to curb their spread.

Finally, the report considers areas in which more research is required before recommendations can be made. Knowledge is particularly lacking with regard to the smallest inhabitants of Antarctica, the microbiota.

1.0 Introduction

1.1 Scope

This report discusses the three components of biosecurity - prevention, monitoring and response, and makes recommendations for improvement in these areas with particular relevance to the New Zealand Antarctic programme in the Ross Sea region. However, the discussion of alien introductions into the Antarctic region is a huge topic, covering a vast geographical area and all human activity in the region. Therefore this report considers only the Antarctic continent and Ross Island, using examples from the maritime Antarctic and sub-Antarctic islands only where these are directly relevant to the species under discussion. Furthermore, this report will consider only those activities relevant to national scientific programmes, and to the New Zealand operation in particular, and thus excludes tourism and fishing. Many recommendations in this report are directly relevant to matters and procedures related to Scott Base and issues which were observed while the author visited the station.

The recommendations made in this report are summarised in the Appendix.

1.2 The Antarctic Ecosystem

Continental Antarctica is a predominantly ice-covered land, with only an estimated 0.34% of area being free from ice and snow (Convey, 2011). These few ice-free areas are generally to be found along the coasts, in the Dry Valleys, and as nunataks – mountains, either individual or as part of a range – protruding from the ice. A very small number of these, such as Mt Melbourne (Herbold, McDonald & Cary, 2014), Mt Rittmann (Bargagli, Broady & Walton, 1996), and Mount Erebus on Ross Island, are known to be geothermal. Human use of Antarctica tends to concentrate on these ice-free areas, for siting research bases, for scientific research and for tourist visits. The predominant reasons for this are the logistical ease of access and biological interest (Potter, 2006). As a result, some of these ice-free areas are extensively used, by national programmes, by tourists, or both, as well as by the birds who nest along the coastline, often in large colonies. Fur seals can also be found along the Antarctic Peninsula (TerraQuest, n.d., para. 9), while Southern Elephant seals come ashore to moult in the summer months (TerraQuest, n.d., para. 7), and occasional young Crab-eater seals are famously known to also come onto land to their deaths in the Dry Valleys**,** an unexplained phenomenon summarised by Baltham (2007).

These ice-free areas have been identified as likely candidates for alien invasion. This is not only because of their natural ice-free condition, but also as a direct result of this human activity altering drainage patterns and causing soil disturbance (Potter, 2006), and by the obviously increased opportunity for human-mediated species introduction that accompanies the presence of more humans. However, such low-altitude coastal areas, with less extreme temperatures than are found inland, are also home to the most diverse range of Antarctic species (Convey, 2015), making invasions particularly harmful to the continent's ecosystem.

The Antarctic biota is generally regarded as being species-poor relative to other ecosystems (Convey, 2015) due to its isolation, its extreme climate and the lack of suitable habitats (Hughes& Convey, 2010). Microorganisms form the largest group in terms of both species and number of organisms (Convey, 2015). Soil invertebrates such as *Diptera, Acari, Collembola, Nematoda, Rotifera, Tardigrada* and *Protista* form the second largest group, followed by basic plants such as liverworts and mosses, and by lichens (Hughes & Convey, 2010). The distribution of populations and species is strongly affected by local features such as height above sea level, wind patterns and precipitation, but generally decreases with distance inland (Hughes & Convey, 2010). Lichens and microbes are the two species found in the most extreme habitats (Hughes, Convey, Maslen & Smith, 2010).

There are large gaps in knowledge about both Antarctic species distribution (Hughes & Convey, 2010) and its trophic complexity (Convey, 2011). However, because the Antarctic ecosystem has many taxonomic gaps (Convey, 2015) it is generally assumed that it also has other qualities - little functional redundancy (Convey, 2015), simple community structures (Hughes et al, 2010a), and numerous ecological niches - which could be exploited by alien species (Convey, 2015). Native species are also believed to have limited ability to compete with invaders (Convey, 2015), and also to recover from disturbances very slowly, an assumption supported by observations in the Arctic, where such recovery can take over a century (Rudolph, 1970).

Species on the continent can be divided into three general categories (Hughes et al, 2010a). The group of species which were present before the last Antarctic glacial maximum even includes a few surviving original Gondwanan species (Hughes & Worland, 2010). The second group is comprised of more recent colonisers which arrived through natural transport throughout the present interglacial period. The third group is made up of colonisers very recently introduced by humans. These recent introductions have the potential to cause significant changes to the Antarctic ecosystem by replacing many of the endemic species (Frenot et al, 2005). While this influx can be said to have the effects of filling unoccupied biological niches locally increasing biodiversity, and increasing the use of available resources (Brown & Sax, 2004), such invasions typically do so by replacing rare endemic species with species common elsewhere and generally regarded as invasive and damaging, such as rats and mice (Cassey, Blackburn, Duncan & Chown, 2005).

Colonisation by natural means involves the transport of propagules (eggs, seeds and plant fragments) or live species on air or ocean currents, often carried along by other animals, or with debris (Hughes et al, 2010a). However Antarctica is kept isolated by ocean and air currents which circle the continent, which must first be crossed. These barriers have been effective in preserving the isolation of the continent from natural introductions (Hughes & Worland, 2010). However, since the advent of humans in Antarctica, this barrier is no longer effective. Substantial invasions have already occurred in the maritime Antarctic and Sub Antarctic islands.

1.3 Invasive Species

An alien species is, simply, one that is not native to an ecosystem and can be introduced by both natural and human routes (Frenot et al, 2005). Three types of aliens have been identified by Frenot et al, according to their behaviour. These categories are transient, persistent and invasive. Transient aliens typically establish small populations which die out naturally within a short time frame. Persistent aliens establish populations and are capable of reproduction but insufficiently to spread from their initial location. Invasive species do spread, often prolifically, and displace other native species in the process. The terms “alien”, “transient”, “persistent” and “invasive” are used in this report as described by Frenot et al, (2005).

Invasive species are generally abundant, can tolerate a wide range of environmental conditions and are often widespread across significant parts of the world (Hellmann, Byers, Bierwagen & Dukes, 2008). They often have a short time to maturity, and invasive plants often have low seed mass which enhances their spread (Hellmann et al, 2008). Invasive plants are often long-lived, with about three quarters being perennial; by contrast the majority (65%) of transient plant species, from examples in the Kerguelen and Possession Islands, are annuals or biennials (Frenot et al, 2005). In this, invasive species are similar to native Antarctic species, which also tend towards life cycles longer than 1-2 years (Frenot et al, 2005). It is also known, however, that it is very difficult to predict which species may become invasive in a given environment (Clout & De Poorter, 2008) although species are more likely to become invasive the longer they persist (Pysek & Richardson, 2010). Species which have shown themselves to be invasive elsewhere should also be regarded with particular suspicion (Houghton et al, 2016).

Pysek and Richardson (2010) stress that whether a species becomes invasive within a given environment depends less upon the absolute characteristics of the alien than upon the match between the alien and the new environment. Some aliens are well matched upon introduction, but others adapt to fit their new home by evolution and hybridisation. Interactions with pre-existing species also play a key role, as a species is more likely to thrive if it has no natural predators or local pathogens. It appears that species that fill, or can adapt to fill, unfilled evolutionary niches in their new environment, have an advantage (Bergstrom & Chown, 1998; Convey, 2015), as will those that can more fully utilise local resources that are not efficiently being used by native species (Brown & Sax, 2004). Both of these make Antarctica particularly vulnerable, as does the established link between some alien invaders and human activities (Pysek & Richardson, 2010). As Antarctica experiences increasing levels of human activity, corresponding shifts in the balance between native and alien species can also be expected. At the same time, climate change may cause Antarctic conditions to be more hospitable to these arrivals.

The impact of an introduced species can have a number of effects on the functioning of the local ecosystem. These range from small effects over long time periods to very significant effects over very short timescales (Pysek & Richardson, 2010). This has already been seen in the wider Antarctica region, with the introduction of an alien blowfly causing a decline in a native fly on the Kerguelen Islands (Gousemett, Hood, Lamers & O’Reilly, 2006), and by the presence of the introduced bluegrass causing reduced photosynthesis by nearby pearlwort and hairgrass on the South Shetland Islands (Molina-Montenegro et al, 2012). In addition, the same species of alien blowfly is suspected of changing the shoreline decomposition dynamics on South Georgia (Gousmett et al, 2006), and an alien midge is thought to have effected similar changes in nutrient turnover on Marion Island (Convey, Key & Key, 2010). Alien species can also themselves be vectors for the transmission of alien viruses, bacteria and fungal plant and animal pathogens (Hughes, Walsh, Convey, Richards & Bergstrom, 2005), instances of which have already been noted on several sub-Antarctic islands (Lebouvier et al, 2011).

Alien species must overcome four hurdles to become invasive within a new environment (Hughes & Convey, 2010). They must be transported to the new location, and must survive the process. They must then survive upon arrival, and go on to establish a viable population with reproductive and long term survival capabilities. Prior to the arrival of humans, the transportation barrier proved very effective at isolating Antarctica (Hughes et al, 2010a), with the result that it is not known what proportion of species would be viable if they were able to reach the continent in a viable condition (Hughes, Lee, Ware, Kiefer & Bergstrom, 2010). It has been theorised that the transportation and climate barriers were particularly significant for keeping out animal species, and that therefore human-mediated transport of new species will be most significant for the introduction of new alien animal, rather than plant, species (Hughes, et al, 2010b).

Climate change is expected to be a significant factor in enhancing the ability of species to survive on the continent. Warming has already been recorded on the Peninsula, and is expected to cause similar changes along the coastline of the continent (Convey, 2011). As warming continues on the Antarctic Peninsula it will change the availability and distribution of freshwater, improving the establishment, flowering and germination of plants (Convey, 2011) in areas where freshwater availability increases. This is supported by evidence from the Antarctic Islands, where increases in alien plants have been seen in the South Shetland Islands (Olech & Chwedorzewska, 2011) and on Marion Island (Ranjith, Shukla, Vennila & Gashaw, 2012). More land may become suitable for colonisation in a similar way to that made available on Kerguelen by the retreat of the Ampere Glacier on Kerguelen, on which land five new alien species have become established (Frenot & Gloaguen, 1994). Climate changes may also have negative consequences for some native soil invertebrates (Frenot et al, 2005). Hellmann et al (2008) have identified five ways in which climate change will have implications for alien species as follows:

- by altering introduction mechanisms,
- by changing environmental constraints on invaders,
- by altering the distribution of existing aliens,
- by changing the impact of invaders and
- by changing the effectiveness of strategies for managing, controlling and eradicating alien species.

1.4 Antarctic Wilderness and Values

It has been argued that the invasion of Antarctica by alien species constitutes a valuable opportunity to research the process of colonisation, and that therefore these invaders should be permitted to remain and spread (Brown & Sax, 2004). However, it should be pointed out that under the Antarctic Treaty, and specifically, under Annex II of the Protocol on Environmental Protection to the Antarctic Treaty (1991), the obligation to preserve the integrity of the Antarctic ecosystems has already been accepted by the Treaty Signatories (Australian Government: Department of the Environment, n.d.). This requires the parties to take measures to prevent the introductions of alien species (except where planned and permitted), with the explicit aim of protecting native flora and fauna (Antarctic Treaty System, n.d.).

These obligations have been actioned in domestic laws in many of the signatory countries. In New Zealand, this became the Antarctica (Environmental Protection) Act 1994, which therefore binds all New Zealand citizens to this obligation **(**Antarctica New Zealand n.d. f, para. 3).

Furthermore, the recognition of the Antarctic wilderness and aesthetic as protected also requires that the Antarctic environment be protected even from alien species that would not be harmful to native species in order to preserve the present character of the area (Clout & De Poorter, 2006). The need to protect the wilderness, scientific and existence values of Antarctica has caused some to argue that the protection of Antarctic wildlife should be considerably more stringent than elsewhere (Clout & De Poorter, 2008).

Protection of the integrity of Antarctic lifeforms from extinction and from genetic hybridisation also has tangible scientific benefits. The extreme conditions which Antarctic lifeforms have evolved to withstand have led to greater understanding of biological processes and their limits (Convey, 2005), while bioprospecting continues for new biological compounds, such as those with antifreeze properties **(**Ranjith et al, 2012).

2.0 Prevention

2.1 Context

Detailed work has been performed to understand the ways in which alien species reach Antarctica. Such understanding can then be used to make changes which reduce the propagule pressure, i.e. the number of viable individuals reaching the continent. These approaches are clearly relevant beyond Antarctica to the biosecurity challenges that face other nations such as New Zealand and Australia. There are, however, two differences. Firstly, continental Antarctica lacks any agriculture (Hughes, Pertierra, Molina-Montenegro & Convey, 2015), the economics of protecting the ecosystem are very different, in terms of motives, practicalities and the sources of funds to carry out protective measures (Pysek & Richardson, 2010). Secondly, the continent is not under the jurisdiction of any single country which means that protective measures co-ordinated between nations must either be agreed by consensus (Hughes & Convey, 2014). Alternatively, measure can be enforced by individual nations on an ad hoc basis. Despite these differences, the analytical methods have proven to be very powerful tools for improving biosecurity practices.

One valuable method is analysing the activities which introduce alien species (McGeoch, Shaw, Terauds, Lee & Chown, 2015). Six of these have been identified as relevant to the wider Antarctic, being scientific activities, tourism, residents, imports of fresh produce, agriculture and airfields. Of these, all but tourism are relevant to the study of national programmes, which support scientific activities, import and grow (hydroponically and in greenhouses) crops, and are served by access to airfields; many of their inhabitants reside in the stations for long periods of time. This approach has allowed detailed analysis by location and activity across the region, including comparisons between locations and identifying areas at particular risk. By identifying the risks it also allows the extent of each threat to be evaluated over time as changes take place in the magnitude and nature of the six activities. The risks identified by this method are particularly relevant for considering monitoring requirements, and will be further discussed in this later section.

Vector analysis is perhaps even more useful as a tool for studying species' introductions. Vector analysis has identified a very broad range of specific routes by which new species enter the region from seeds captured on clothing to cargo packaging, food and timber imports, and the hulls of ships and aircraft (Houghton et al, 2016). Direct intervention methods have been made possible by detailed investigation of each vector in turn (Pysek & Richardson, 2010) leading, for example, to greater education programmes to travellers of the risks (Whinam, Chilcott & Bergstrom, 2005), cleaning of boots (Hughes & Convey, 2010), redesign of clothing to avoid the use of Velcro (Whinam et al, 2005), fumigation of cargo (Hughes & Convey, 2010) and redesign of crates (Potter, 2006).

Even more detailed research has looked at the differences in species transported by each route (Houghton et al, 2016), which has clear implications for the effectiveness of different eradication chemicals and methods en route.

2.2 Clothing and Personal Items

While much of the focus has been upon the propagule loads carried by tourists on their clothes and boots, it is clear that scientists are at least an equally significant route of introductions. One study (Chown et al, 2012) found an estimated 31,732 seeds transmitted by 33,054 tourists and tourism-related personnel, and 38,897 seeds carried by scientists estimated as numbering 7085, over the same period. The scale of problem that scientists represent does not seem to have received the same attention in the literature as that posed by tourists.

The numbers of both scientists and tourists appear to be increasing, though the number of tourists remains approximately ten times that of scientists (Molina-Montenegro et al, 2014). However, as these researchers point out, scientists remain on the continent longer than tourists, require considerable logistical support involving the import of substantial cargo and the construction and maintenance of buildings. They assess scientific activity to be greatest during summer melts when both vegetative and animal reproduction peaks, and they, like tourists, are concentrated in the ice-free areas. It should be added to this list that scientists interact on a more intimate basis with the environment, camping in remote areas, handing wildlife, and entering remote and/or protected areas such as the Dry Valleys, where few very tourists visit. In addition, scientists operate in a very different supervisory environment. Compared to tourists, who are supervised by tour operators, scientists are more independent and have greater scope for making mistakes while overcoming problems which impede their data and sample collection. As Convey (2015) points out, a single mistake by a single individual can cause significant contamination of the environment.

Tourists have been found to have a limited range of clothing for cold destinations (Huiskes et al, 2014), with the risk their clothing and gear may thus be contaminated with alien species already well adapted to cold conditions. It has similarly been highlighted that scientists are also likely to conduct research in other cold climate areas, such as the Arctic, with the risk that their clothing and equipment may similarly transmit species that have traits favouring survival in the Antarctic. Huiskes et al found that footwear, trousers and bags were particularly risky for members of national science programmes. Another risk factor for these travellers was whether they had recently visited protected, alpine or parkland areas prior to travel (Huiskes et al, 2014).

Several recommendations can be made in this area. Firstly, that Antarctica New Zealand should not, when preparing passengers for departure, require that the bags be set out on the central grassed area of the Antarctic Centre for labelling, as was done for the PCAS group's departure in December 2015. This procedure could easily be moved to an indoors location, such as the Antarctic Terminal waiting room, or within Antarctica New Zealand's logistics building. Secondly, that travellers be required to fill out departure cards regarding their movements over a suitable timeframe prior to travel, in the same way that arrival cards for visitors to New Zealand are required to declare whether they have had contact with farm animals or visited wilderness areas while abroad. Thirdly, checks should be carried out on the footwear of outbound passengers in the same way that checks are made on boots being brought into the country; and it may be valuable to extend this to include the hems of trousers as well. Fourthly, spot-checks should be carried out on leavers, and fifthly, a bio-security dog could be used to search for contaminated clothing. Finally, travellers should be required to declare any foodstuffs carried and declare that these are in a clean and/or sealed state. In particular, fruit should be visually inspected to ensure that it is free from visible soil or mould contamination. In light of the procedures which visitors and returners regularly undergo at airports when returning to New Zealand, it seems a particularly strange omission that very similar checks are not carried out on flights leaving for a destination with an acknowledged fragile ecosystem and which is claimed as New Zealand territory.

Because clothing has been identified as a route for significant seed transfer, Antarctica New Zealand would be well advised to consider amendments to its processes regarding the issue of clothing, specifically allowing travellers to take these clothes home with them in the time between clothing allocation and travel. Australia has particularly stringent rules relating to clothing worn on journeys to the Macquarie islands (Australian Antarctic Division, n.d.). However, such recommendations have been made before (Gousemett et al, 2006).

There are a number of complications regarding personal equipment, and there would be considerable resistance to a ban on personal clothing and boots. These might in any case not be practical where individuals have particular medical requirements e.g. orthopaedic. Australia's policy of "take it new or keep it clean" (described in Gousemett et al, 2006) somewhat misses the point that even new items may already be contaminated (Whinam et al, 2005). For these reasons, it is not suggested in this report that individuals be barred from taking their own items, but rather that an element of supervision is introduced into the process to ensure that the items are indeed clean.

2.3 Food

Food is another significant risk for transfer of species to Antarctica. Antarctica New Zealand have gone to considerable effort to ensure robust procedures, with detailed guidance regarding which fresh foods may be imported to Antarctica, the checks that should be performed on each before sending, the packaging of the produce, and the procedure for the chef when unpacking the goods, alien species are still transported alive to the continent within food shipments (Antarctica New Zealand, n.d. a**;** Antarctica New Zealand, n.d. c). However, the author observed a fellow diner at Scott Base discover a green caterpillar - very much alive - within his salad. It is not known whether a report was made of the incident. It is acknowledged that food is a known and common problem for all nations with bases in Antarctica, and that even the most thorough inspections cannot prevent pests being imported (Potter, 2006). Nor is fumigation always effective; pests have been found in cargo bound for Macquarie Island even after ozone treatment (Whinam et al, 2005).

Technology does already exist to significantly reduce the vast majority of food related alien imports, in the form of food irradiation. Irradiation of food is an internationally-recognised way to eliminate pests, typically from exported fruit and vegetables. It is a safe and fast method to treat foods to eradicate pests (UW Food Irradiation Education Group, n.d., para. 2 and 6) which is typically performed after the food has already been packaged and sealed for transport. It has been approved in Australia and New Zealand for the treatment of some types of produce (Food Standards Australia New Zealand, 2014, para. 8).

As well as being effective at low doses against invertebrates, irradiation is also effective at higher doses against food-borne bacteria such as those causing *Salmonella, Campylobacter* and *Esherichia coli* (National Center for Emerging and Zoonotic Infectious Diseases, n.d., para. 2). These diseases, being highly communicable and serious, are a threat to the well-being of humans in Antarctica. They are also potentially transmittable to Antarctic wildlife, both through direct consumption of food scraps and through sewage discharge. Salmonella strains have been found in Adelie, Gentoo and King penguins (Grimaldi, Seddon, Lyver, Nakagawa & Tompkins, 2015) and other Antarctic seabirds (Palmgren et al, 2000), while both salmonella (Palmgren et al, 2000), and Campylobacter have been found in Antarctic seals (Garcia-Pena et al, 2010). The discovery of Campylobacter in Macaroni penguins has been tentatively identified as an introduction to the Antarctic area (Griekspoor, Olsen & Waldenstrom, 2009**)**. The transmission of these diseases is a major cause for concern even though, as Grimaldi et al (2015) note, the effect that these diseases have on the wellbeing of these animal populations is generally not clear. However, food irradiation could not be used to eradicate viruses potentially carried on food as viruses are highly resistant to radiation, even at very high doses. This includes poultry viruses such as infectious bursal disease, commonly found on commercially raised poultry and for which there is evidence of immunity, indicating prior exposure within Antarctic penguin populations (Grimaldi et al, 2015)**.**

Despite the suitability of irradiation for cargo destined for Antarctica, it is clear that irradiation is unlikely to be a short, or even medium-term solution to the problem. This is because of public opposition to irradiated foods, the limits on Australasian approval for food irradiation, and the lack of suitable facilities to supply irradiated food from Christchurch. However, it is recommended that the feasibility of supplying irradiated foods be periodically reviewed.

Similarly, with regard to the possibility of transmitting food-related disease to wildlife, a review should be made of the forms of meats supplied to field camps. In particular, it should be considered whether uncooked meat, whether chilled or frozen, and freeze-dried meat should cease to be supplied to field camps (Australian Antarctic Division, 2008), unless it has been adequately prepared for eating by another method, such as smoking or salting.

2.4 Business Processes Review

A useful exercise for Antarctica New Zealand to carry out on the prevention (quarantine) aspects of its operations would be a full business processes review. This is a comprehensive investigation into the nature of employees' roles and their tasks which many businesses find useful in a number of ways. It can, for example,

- lead to more efficient allocation of tasks between employees,
- identify training needs,
- assist when hiring and during performance reviews,
- identify areas for improvement such as stocks of essentials running low (e.g. the female urinary directors which could not be supplied to our group with sufficient time before departure to practice their use),
- show areas where cost savings can be made, and also
- highlight areas where current practices expose the organisation to undue risks (health and safety, publicity, environmental, litigation).

A business process review should highlight the tasks that each employee carries out and the method used, as well as the location the tasks are performed in. Such an analysis would, for example, show that pre-travelling labelling of luggage is currently carried out on a grassed area. The results of such an analysis would then enable changes to be made where appropriate and feasible.

Both departure procedures and cleaning procedures after return should be included in this review.

3.0 Monitoring

3.1 Context

Quarantine measures to prevent alien species reaching Antarctica have, historically, tended to be the focus of biosecurity measures. This is because, despite quarantine procedures being costly and time-consuming, the cheapest and easiest way to deal with invasions is often by pre-emptively preventing them from occurring (Pysek & Richardson, 2010). However, the realisation that quarantine measures can never be completely effective has led to greater emphasis on monitoring and response. Incidents such as Poa annua invasions and the fly invasions at Rothera and Casey stations appear to have been discovered only at the point that the invasions became manifest. By contrast, effective monitoring should be an active process of checking before any overt signs of a problem become apparent. Monitoring is not a necessary precursor to response, since many invasive species will eventually become obvious by themselves. But monitoring offers a better chance of achieving effective response by discovering and eradicating alien populations before they become too large and too established to be destroyed, and by collecting data about transient invasions, which might otherwise not be discovered at all.

In some instances, monitoring for pest invasions in the Antarctic seems to have been carried out in response to incidents rather than being proactive. Fly traps and electric fly killers were installed at Rothera station only after their fly infestation was discovered (Hughes et al, 2005). There is a very real danger of precautionary monitoring measures being seen as excessive and unnecessary until such time as they are proven otherwise. However, a recent survey by COMNAP found that National Antarctic Programmes who conducted research into the subject of invasive species were likely to improve their own monitoring and surveillance procedures, perhaps indicating that in some cases the results of the research came as an unpleasant shock to some countries (COMNAP, 2008).

3.2 Recent Progress in International Monitoring Measures

It has been noted by McGeoch et al (2015) that the lack of a system for tracking invasive species in the Antarctic, and the lack of an established baseline for identifying trends, has been a huge gap in the monitoring process. These researchers have recently carried out significant work in this area, with the result that this work may now be used going forward to identify trends and reduce risks relating to invasive species in the Antarctic region

In addition, McGeoch et al (2015) also noted the lack of a system for formally documenting impacts of and responses to aliens, for sharing information and answering questions relating to interventions and policy developments on the issue. This too has been addressed in recent years, with the Antarctic Treaty System reports “Colonisation status of known non-native species in the Antarctic terrestrial environment 2010” and” Colonisation status of known non-native species in the Antarctic terrestrial environment (updated 2013)”. These collations of known invasions have done much to allow such tracking as McGeoch et al call for. There is now hope that monitoring of invasive species can be co-ordinated internationally, guidance issued to promote effective monitoring techniques, and an enhanced level of international communication and accountability.

In addition, as Convey (2011) notes, the Committee for Environmental Protection of the Antarctic Treaty System now has the introduction of new species as a standing agenda item. It is hoped that this will help to ensure that all known instances of alien species in the region are recorded and communicated**.**

The Australian Antarctic Division has since 2004 compiled a searchable database of all invertebrates found – whether captured or not - on stations, supply ships and aircraft in the Antarctic (Houghton et al, 2016). This has yielded some very interesting results; the numbers and types of species found in particular places and, in some cases, whether the specimen was still alive upon discovery. From this information, it is now identified that some species survive fumigation processes by being deep within the food, and that winged species can arrive on the ship through flight, thus evading dock-based quarantine processes. Furthermore, and perhaps unexpectedly, it seems that most of the invertebrates discovered were live adults at the time of transportation rather than in an egg or larvae form. The collation of similar records by New Zealand would be a very useful addition to this.

3.3 Flies and other Invertebrates

Flies are now known to be a particular problem in Antarctica's stations, whose buildings provide suitable conditions for colonisation. The fly problem at Rothera seems to have been eliminated, but Scott Base has had a number of incidents involving flies and other insects (Antarctica New Zealand, n.d. d), and the black fungus midge that infested the Casey sewage system has not been eradicated (Hughes et al, 2015). More broadly within the Antarctic region there are a number of similar instances of invasive alien fly populations becoming established. The Diptera fly infested the sewage system at the Artigas base on King George Island and has been similarly persistent, now being found 4km from the station ("Colonisation status", 2010). Hughes, Pertierra, Molina-Montenegro and Convey write that "While successful eradications have occurred within station buildings and hydroponic facilities, no successful eradications of non-native invertebrates have occurred within Antarctic sewage treatment systems" (Hughes et al, 2015)

Various monitoring techniques are already carried out at Scott Base, including fly traps and roach traps. These appear to be concentrated in the kitchen and the Hillary Field Centre (HFC) (Antarctica New Zealand, n.d. d). The traps in the kitchen form part of the process for opening and inspecting freshly imported produce, whereas the HFC traps appear also to have been prompted by food related incidents; one is positioned near the beer store. It is not stated in the documentation that there are any traps in or near the waste processing area and, if there are indeed no traps here, this is a notable omission. Insect traps around the sleeping and laundry quarters should also be considered. Bedroom quarters are also an area where people may store food or empty out clothing with crumbs caught in it; the author was bitten while sleeping by an insect which appeared to be caught up in the bed linen. Insect traps are a low-cost method for early detection, and this should be relatively easy to implement, although some communication with the rooms' inhabitants may be necessary to co-ordinate checking the traps with the rooms' availability.

As well as in these areas within the base building proper, it is also strongly suggested that insect traps be positioned within and around the containers and outbuildings. Some containers, such as those containing imported wood products such as bamboo canes, are obvious candidates for monitoring. However, all structures can provide shelter for insects in the same way they are known to provide shelter for plants (Molina-Montenegro et al, 2014), and therefore monitoring procedures should not be limited to these containers.

It is known that in the past the fly traps at Scott Base have not been checked as required (Antarctica New Zealand, n.d. d), and it is not clear whether they were being checked as per the weekly schedule during the PCAS group's visit. There was a gap of at least two weeks between the first known insect bite and official recognition of the problem. It is equally plausible that the traps were simply in the wrong location to detect the problem, or that the insects in questions were not flies.

Scott Base procedures give detailed advice for returning specimens of flies, and other invaders, discovered at the base, back to New Zealand for analysis, (Antarctica New Zealand, n.d. b). The level of detail of this advice is commendable. Detailed understanding of the stages that a species passes through can be powerful knowledge when planning eradication, as certain methods may not work as effectively on larvae and eggs as on adults. Clues may also be obtained as to what the species is feeding upon, which might in some cases involve another, undetected, alien species. In addition, information regarding transmission routes can sometimes be obtained using DNA evidence (Chown, Sinclair & Jansen van Vuuren, 2008; Jansen van Vuuren & Chown, 2007). With the recent development of portable DNA testing devices, it might be possible to carry out preliminary analyses of samples without waiting for transport to New Zealand (Perez, 2013). Alternatively, similar facilities might be available for use at McMurdo to expedite the start of eradication.

3.4 Plants

With regard to invasive plants in the area, it is not known what procedures, if any, exist to monitor the disturbed ground around Scott Base, which is a particularly attractive environment for the establishment of grass species. Much of the base area is subject to heavy traffic, which would both decrease the likelihood of plants becoming established, and also increase the likelihood of a plant being spotted. However, there are areas, such as under the buildings around the snowmelt line, under or around the containers, and behind out-buildings, where an invasive plant could perhaps establish itself and come to seed without being spotted. It is therefore recommended that regular inspections be carried out around areas of the base assessed as being at higher risk. The frequency of inspection should relate to the likely time that an invasive species, such as *Poa annua*, would grow from a shoot to reaching the point of seeding.

Monitoring for any possible spread of plant propagules to the area outside of the base is an immense challenge, and one that should properly be the focus of planning at an international level. In the meantime, attention should be paid to ice-free areas near to the base and near to those areas used for recreation (such as Castle Rock) and research. A thorough inspection of these is clearly neither practical nor even possible, given the size of the areas concerned and their challenging terrains. Inspections might well pose a higher risk for introducing new propagules than discovering existing ones. However, inspection of the area using binoculars from suitable vantage points might be feasible. Such inspection should also be made of Crater Hill and the cliffs outside Scott Base. Both these locations are vulnerable to introductions due to their proximity to the base and would be extremely challenging to eradicate invasive plants from if they had had the opportunity to spread over a large area.

3.5 Waste

Antarctica New Zealand has stringent procedures to ensure that human waste is returned to the station for correct disposal. However, this has not always been the case, and global warming is currently causing melting of the snow cover on a number of historic lavatory sites. Human, dog and pony faeces have been identified in such deposits on the Peninsula (Hughes and Nobbs, 2004). The area around Scott Base has been used for exploration since the earliest days of Antarctic exploration, and thus there is reason to suspect that such sites also exist in the vicinity of Scott Base.

There also remains the ongoing risk of contamination due to human error. A pee bottle was recently lost by a member of the PCAS group while descending the rock face of Castle Rock. This is a reminder that waste accidents are likely to occur despite best precautions. The bottle was not able to be recovered due to the steep nature of the terrain, and it is not known whether it is survived the descent intact or whether it burst open against the rocks.

Not all bacteria can survive the cold, but faecal *Enterococci, Bacillus* and *Clostridium* have been found to survive for 30-40 years and it is thought that sporing bacteria such as *Bacillu*s and *Clostridium* may survive for considerably longer (Hughes & Nobbs, 2004). All known historic campsites should therefore be monitored for signs of melting, and it may be possible to use radar and other techniques to ascertain whether any rubbish dumps or latrines are present. An assessment should be made on a site by site basis whether it would be safer to leave the area untouched, or to remove the rubbish while still frozen.

Kitchen and sewage waste have been identified as routes for the introduction of a range of new bacteria, including diseases that may be transmitted to wildlife (Potter, 2006). More research is required on the dangers regarding kitchen waste, but sewage is already a known concern. The sewage-related bacterium *Clostridium perfringens* has spread 800m from the McMurdo sewage outfall (Gousemett et al 2006), and antibiotic resistant *Esherichia coli* has been found near to a research station in the maritime Antarctic region (Grimaldi et al, 2015).

Both McMurdo and Scott Base stations have sewage treatment facilities, with the McMurdo treatment process being more extensive than the New Zealand process. However, as bacterial contaminations have been found associated with the McMurdo site, this may suggest that there is room for improvement of both. More research is needed regarding the nature and extent of these risks, as improvements to the Scott Base sewage system would no doubt be costly and inconvenient, and might still not address all the associated risks. In particular, research is required upon the effect of human-transmitted diseases upon infected Antarctic wildlife, as the consequences of infection are generally still not known (Grimaldi et al, 2015). Special consideration should also be given to the problem of antibiotic resistance. It is unlikely that significant changes will be made in this area without solid research to justify improvements, and/or without significant change in current technology.

3.6 Biosecurity Officer

Ships to the Macquarie and Heard Islands have for some time been accompanied by biosecurity officers. This has resulted in improved understanding of the risks among travellers and staff, and a notably reduction in the quantities of alien material discovered (Whinam et al, 2005). A similar – fulltime - position created at Scott Base would permit a more pro-active approach to the ongoing problem of alien invaders. The responsibilities of this position could include responsibility for liaising with visitors and permanent staff, for educating, for inspecting and for managing information flow to other bases in the region.

A biosecurity officer would be ideally placed to carry out the inspections for plants noted above and, if suitably skilled, might also be able to carry out DNA analysis of samples previously discussed. In addition, a number of specific examples, as noted from the PCAS group's recent visit to the station can be cited. Firstly, by liaising with the transient population of scientists and students, incidents might more reliably be reported, such as the caterpillar and the insect bites. The author discovered a very fresh insect bite on her first morning at the station and reported it to a field trainer, but as the trainer believed the bite could have happened previously, no further advice was given or action taken. Two weeks later, an announcement was made at the Saturday afternoon meeting, that a number of bites had been reported and a request was made to anyone who had also been bitten to report it. Upon doing so, the author discovered that her initial report had not been passed on, and at that time it transpired that a number of other members of the group had also been bitten. Had the PCAS group been scheduled for departure two days earlier than planned, we would have missed this meeting, and our incidents would not have been recorded.

Secondly, a biosecurity officer would also be well placed to investigate the apparent potted plant at Square Frame Hut. Such potted plants contravene the Environmental Protocol (Hughes, Pertierra Molina-Montenegro & Convey, 2015). In recent years there has been considerable pressure to remove such items from station buildings as they constitute both a disease risk upon importation (Smith, 1996; Potter 2006) and may harbour other alien species which are later introduced.

3.7 Reporting System Improvement

Scott Base does have an incident reporting system which in theory should have been suitable for recording the insect bites experienced by multiple members of the PCAS group. However, our group was not shown the reporting system, and the author was not advised to file an official report of her bite. Furthermore, intranet reporting systems, while they may be adequate for established groups of employees, are not as suitable for transient individuals, who are unlikely to be familiar with the base's (many) processes in general and their intranet in particular. These visitors may be extremely busy and perhaps somewhat overwhelmed, and may have difficulty getting access to one of the few computers available for public use. In such a case, an identified biosecurity officer could be an invaluable point of first contact. In their absence.

It is also recommended that field trainers ensure all reports of such incidents are made - even if this requires them to make the report themselves. A helpful measure would be paper forms to make reports on – perhaps even issued as part of the introductory process. Copies of this form could be kept at the Comms office, since this is always manned, and in the mess hall, since the caterpillar incident is likely to be fairly common. As well as improving the proportion of incidents that are reported, this would also facilitate the promptness and accuracy of reporting.

With regard to reporting, it would also be helpful if the procedures for reporting incidents were to be prominently displayed around the base, perhaps on A1 sized posters similar to those already on display.

3.8 Risk Based Monitoring

Effective monitoring is at its heart a risk-based procedure; as resources are limited they must therefore must be targeted effectively and intelligently at areas of higher risk. Analysis of activities is useful in identifying particular pathways of increased risk. For this reason, it is useful to know whether the nature or scale of particular activities in particular regions are increasing or decreasing.

Charting changes in the activities conducted from Scott Base would be an interesting area for further research, and could highlight other areas where more prevention and monitoring are required. For example, an increase in the risk associated with air travel could be due to an increase in the amount of helicopter flights from the base, changes in their destinations (particularly relevant with the current focus on supporting research needs at increasingly remote sites) and even the recent use of a drone operated from the base site.

The nature of risks also changes seasonally over the year, as does the effectiveness of monitoring techniques (Montoya, Rogers & Memmott, 2012). Risks from food imports during the summer months change to those presented by the over-winter hydroponics system (Antarctica New Zealand, n.d. e). However, the increase in winter flights to McMurdo may change this profile if fresh food supplies for Scott Base are included on these flights. In principle, if these flights continue to be operated monthly throughout the winter as currently planned, there may be a reduced need for the hydroponics system. Flights are correlated, in many bases, with newly discovered fly invaders (Hughes et al, 2011), most likely associated with food imports. Therefore the overall winter risk of flies may increase in future due to the increase in flights, even if the hydroponic system were no longer used. The combination of both a hydroponics system and monthly winter flights might be particularly risky. Many stations have had incidents of infestations of their hydroponics facilities, including the US, New Zealand and Australia (Hughes et al, 2015), and this area remains a risk, albeit one which Antarctica New Zealand knowingly accepts and mitigates with cleaning and inspection procedures (Antarctica New Zealand, n.d. e). Going forwards, however, this acceptance may need to be reassessed due to the increase in winter flights.

One activity not in the list of risky activities described by McGeoch et al (2015), but identified by a number of authors, is that of construction. Imported building sand in the 1980s is believed to be the source of two plant introductions on Marion Island (Gremmen & Smith, 1999). Station construction is estimated to account for 2,000-3,000 imported seeds per year of work (Huiskes et al, 2014). A number of alien lichens (Osyczka 2010), fungi and invertebrates have been identified in timber imports (Osyczka, Mleczko, Karasinski & Chlebicki, 2012).

Major building work is currently being carried out at Scott Base. While it seems now to be increasingly accepted that timber used for construction should be pre-treated and be imported without bark, it is not plausible to think that all threats associated with these imports, including microscopic spores and insect eggs, can be wholly prevented. Therefore, this project represents a significant increase in risk at the station which will need to be compensated for by monitoring which is increased both in distribution and scope. Areas of disturbed ground are known to be particularly prone to invasion by alien plant species, due to modification of soil nutrient levels as well as the enhanced opportunities for introduction and dispersion (Molina-Montenegro et al, 2014). Since building work causes a large amount of ground disturbance, the elevated risk associated with this and other building projects must be treated as a long term risk increase requiring a correspondingly long-term increase in monitoring.

4.0 Response

4.1 Context

A key difference between monitoring and response as policies is that response is most likely to be agreed to, and carried out through co-ordinated action, between governments, or by an individual government’s policy effected through the actions of their National Programme personnel. By contrast, monitoring may be carried out at this international level, at an individual country level, by individual scientists without implying buy-in by their respective governments, or by international organisations such as SCAR.

Historically, responses to discovered alien populations seem to have been carried out on an ad hoc basis. While half of nations surveyed declared that they had a response plan, many of these were extremely limited in scope (De Poorter, Gilbert, Storey & Rogan-Finnemore, 2006). Most countries are still gathering information rather than formulating comprehensive strategies, and there seems to be a lack of co-ordinated response plans (Gousemett et al, 2006)**.**

As invasions have generally been discovered in, or very near to, national research stations, the responsibility for response has generally been clear. However, in at least one instance, that of the *Poa annua* grass at Arctowski station, the response was for many years no response, resulting in an expansion of the grass population to the extent that it is now threatening a nearby ASPA (Pertierra, Lara, Benayas & Hughes, 2013). Within the wider Antarctic region there are several examples of both ASPA and ASMA areas being threatened or invaded by alien flies, springtails, grasses and a rush ("Colonisation status", 2013). On the Peninsula, there is concern regarding the continued delay in removing the population of *Poa pratensis* at Cieva Point (Hughes & Convey, 2014**)**. In other instances the responses have been unsuccessful (Hughes et al, 2015). The eradication of invertebrates seems, from examples within the wider region, to be a particular problem. Although a number of alien plants have been eradicated from the Peninsula and nearby islands, no removal has been attempted for invertebrates, despite the instances of alien invertebrates increasing (Hughes et al, 2015).

There does not currently seem to be sufficient will across the Antarctic Treaty signatories to establish a unified response policy. There are undoubtedly many reasons for this. Political motives, such as not wanting to be told how to administer the area within and around each country's base, are undoubtedly significant. However, there may also be practical reasons, such as that the environments around the various bases may be so different, and the activities undertaken from them so varied, that standardised policies may be of very limited use.

If indeed such reasoning plays a part in the apparent reluctance by countries to develop co-ordinated response plans, three options are open to any country with the will to develop an effective plan. One is to develop procedures with as many of the signatory countries as are similarly inclined. The second is to pursue common agreements with nearby bases. In New Zealand's case this would mean the US at a minimum. Thirdly, New Zealand can develop its own procedures and hope to lead the way in this area.

A notable exception to the absence of co-ordinated response plans is the recommendations of the Workshop on Diseases of Antarctic Wildlife, hosted by the Australian Antarctic Division, regarding animal mortality events (Australian Antarctic Division, 2008). This document gives detailed and comprehensive guidance regarding routine monitoring of populations, identifying an unusual event, for standardised sample collecting, for avoiding contamination, and for reporting. This document and its recommendations could form the template for broader discussions on imported species. It would also be valuable to consider the people and processes involved in this workshop which produced this document, for example by interviewing key participants.

4.2 Planning an Effective Response Strategy

With regard to successful eradication, it has been stated that detailed knowledge of the species and its lifecycle can be essential to achieving a successful result (Hughes et al, 2015). In addition, the same authors state that extensive planning of the eradication regime is required, along with detailed risk. However, these requirements are in clear opposition to the requirement to act quickly, while populations are still small, localised, and may not be fully established within the local ecosystem.

How are these two competing requirements to be balanced? One answer to this is by carrying out as much of the planning process as is feasible before discovery of an invasive population. As Dwight D Eisenhower famously said (as quoted by Notable Quotes, n.d., para 8), "In preparing for battle I have always found that plans are useless, but planning is indispensable".

Therefore, a significant way forward in this area would be for delegates of countries with bases in Antarctica to participate in a workshop to develop a common response plan for dealing with invaders. It would be helpful if countries were prepared to table their existing plans for discussion and criticism, however this level of participation should not be made a condition of attendance. New Zealand would be ideally placed to develop its own set of ideas for discussion in this manner.

However, if international discussion is not possible to arrange, or if it is unlikely to be arranged in a reasonable timeframe, New Zealand policymakers should consider having such discussions internally. An area that would be particularly important to develop is specific plans tailored to particular species already known to present especial problems in the region. A number of scenarios could be worked through, relating, for example, to the following: an extensive population of *Poa annua* on the cliff face near to Scott Base; an infestation of flies in the sewage system; an invasion of rats, or mice, in a nearby animal colony; an outbreak within the station of a disease capable of transfer to local animal populations; a virus with harmful implications for the native lichen; the introduction of toxic algae. For this to be comprehensive, a number of experts should be consulted so that a full range of invasive species could be included in these scenarios.

Neither rats nor mice have been reported on the continent and are thought not to be capable of becoming established there (Hughes & Convey, 2010). However, these species have been identified as having potential for causing large damage to bird colonies in even the short term, and there remains the possibility that a population may become established within a research station (Hughes & Convey, 2010). Therefore it would seem unwise not to plan for the damage that even a single individual could cause.

4.3 Specific Key Issues Identified

There are some key issues relating to response that must be addressed before effective response plans can be formulated. One of these, relating to plants, is that some species may not grow in the Antarctic region in the same way that they do elsewhere, and therefore may not immediately be identifiable as an alien. *Poa pratensis* does not produce seed in its location in the Peninsula while Antarctic *Poa annua* grows in tussocks very different to its growth elsewhere (Wodkiewicz, Ziemianski, Kwiecien, Chwedorzewska & Galera, 2014). Five alien species, albeit species believed to be transient, were found near Progress II in the Larsemann Hill region of East Antarctica (Hughes & Convey, 2010). Only two of these (*Puccinellia distans* and *Alopecurus geniculatus*,) were grasses, the others were the flowering plants *Stellaria media, Rumex pulcher* and *Chenopodium rubrum*. This indicates that advice given to assist in identifying alien plants in the Ross Sea Region will need to be very comprehensive and not assume that alien species will necessarily be members of grass families.

Consideration will be required regarding treatment of species found in distant locations which cannot readily be identified. Should these be removed immediately in the "shoot first, ask questions later" policy advocated by some (as discussed by Hughes et al, 2015)? This risks contravening the Treaty by removing a previously-unidentified native species. However, an invasive plant species allowed to remain in place may very quickly seed, potentially contaminating a wide area. A protocol addressing this question will need to be put into place pre-emptively, since real-time identification from the field by screenshot sent by mobile phone is not currently possible. For animal pests, detailed instruction will be required for the capture and/or killing of animal pests, which risks attracting negative publicity when details of the guidance reaches the media.

Another problem is the issue of whether plants have been brought to the area by humans or by natural processes, since if they have been brought by natural processes they might be considered potentially native and therefore protected (Convey, 2015). This is a greater problem for the Peninsula region than for the Ross Island region, but the alien moss *Pohlia nutans* has been identified in the biota of the Mount Rittmann thermal region (Skotnicki, Bargagli & Ninham, 2002), and *Campulopus pyriformis*, a moss native to the South Sandwich Islands has been found on geothermal ground around Mount Erebus and Mount Melbourne (Herbold et al, 2014) in what have all been speculated to be natural introductions. Guidance will increasingly be required, as these populations expand and as new ones are discovered, as to whether they should be removed or allowed to grow.

The question has also been asked whether it might, in some circumstances, be considered acceptable to use herbicides and pesticides, which are currently prohibited in the area for such use by Annex III (Hughes et al, 2015). Glyphosate has been used to eradicate a species on Marion Island (McGeoch et al, 2015). In most Antarctic ASPA areas such chemicals are banned, but the use of herbicides was pre-emptively written into the plan for ASPA136 (Hughes et al, 2015); their use elsewhere remains at best a grey area. Furthermore, there are concerns as to the effectiveness of chemical methods in cold temperatures, and more research would be required in this area (Hellmann et al, 2008).

It has been said that in many cases plant species could effectively be eradicated by "a person with a spade" (Hughes et al, 2015). This comment likely remains true in the majority of cases which are small and localised to the areas around bases. However the possibility remains of a plant invasion in a remote area, such as the Dry Valleys, which is not discovered until it became extensive. As Pysek and Richardson (2010) note, there is an inherent contradiction between invasive species and early detection since invaders are rare and early detection of isolated instances is very difficult.

The area of invasion is inversely related to the probability of successful eradication. In California, when the affected area is under 100 hectares, eradication has a 30% chance of success, but when the area is greater than 1000 hectares, eradication is considered extremely likely to fail (Pysek & Richardson, 2010). One question which would be valuable to answer is, what are the appropriate comparable areas in the Antarctic region? Would larger areas be easier to eradicate, because of slow growth rates? However, Hughes et al (2015) note that eradication attempts fail if native species are also eradicated in the area, thereby making future invasion more likely; hence even areas smaller than 1000 hectares may in the Antarctic be unrecoverable.

In cases where a species has spread so far that its removal would be unduly damaging to the environment, such as the spread of the Signy Island midge (Hughes & Convey, 2014), consideration should be given to how this is to be ascertained before irreversible damage is done to the environment in the attempt.

When Scott Base formulates its response plans, the guidance relevant to base staff should be prominently displayed on posters on locations around the station.

4.4 Other Considerations

Evidence from elsewhere in the world has yielded a number of helpful observations about successful eradication programmes. Pysek and Richardson (2010) have identified reasons for failure which include

- failure to understand the target species,
- failure to obtain local co-operation,
- failure to adequately map the species' spread,
- failure to make available adequate resources,
- failure to regularly re-evaluate the process.

In particular, the cost of eradication projects can be significant.

A cautionary tale that may yet play out within continental Antarctica is the collapse of food webs due to the removal of an alien species. This is unlikely to occur by meso-predator release in the way that has been observed elsewhere (Pysek & Richardson, 2010), but could still occur if an alien population is left in place long enough for a native species to become reliant upon it for food.

Some consequences of invasions will not be able to be corrected by the removal of the alien responsible. An example is the enhanced nitrogen levels in soil caused by nitrogen-fixing alien plants, which have been found to make the area vulnerable to reinvasion (Pysek & Richardson, 2010). The only current solution to such problems appears to be prompt removal to minimise the number and area of sites thus affected.

There are also a number of unanswered legal questions, such as what conditions an invasive species would have to satisfy before it was considered an emergency (Hughes et al, 2015; Hughes & Convey, 2014), what legal liability might attach to a country if its citizens were found to be the cause, and what the likelihood would be of successful action taken against that country (Hughes and Convey, 2014). It is not clear whether the Liability Annex, when it comes into force, would make it possible for one country to clear up the area around another country's base, and then recover the costs via legal action (Hughes & Convey, 2014); it is even less clear that such an action would be politically acceptable.

A useful investigation which might be carried out in this area would be a failure analysis of the Casey Station sewage system fly infestation, to determine the point at which the invasion became untreatable. It would also be useful to ascertain the reasoning behind decisions which have left populations of alien species in place without eradication attempts. Such discussions with base leaders could be difficult to obtain, but any insights into the decision would be very valuable.

4.5 Other International Contributions that New Zealand Might Make

New Zealand could make a difference by advocating the updating of the Environmental protocol to explicitly cover unintentional introductions, and to cover intra-Antarctic species introductions (Hughes et al, 2015).

Hughes et al (2015) also observe that the current Protocol does not distinguish between alien invaders and persistent or transient invaders. However, any amendment to this would probably be ill-advised since the difference between these categories is based upon behaviour alone. Therefore plants can only be categorised on the basis of past behaviour, which does not necessarily predict future behaviour. As Clout and De Poorter write,

“The lag phase of a future invader is often indistinguishable from the slow rate of spread displayed by alien non-invasive species in a new range” (Clout & De Poorter, 2008, p16)

New Zealand could also advocate for the creation of a central fund for environmental projects such as eradications, as suggested by Hughes et al (2015).

5.0 Limitations of the Above Recommendations

This discussion has concentrated heavily on plants and flies and (to a lesser extent) lichens, other invertebrates and bacterial and viral diseases. Many of these categories have not received the attention they deserve.

5.1 Microbiota

There has been considerable concern in some quarters about the microbial contamination of Antarctica (“Introduction of non-native species in the Antarctic Treaty Area: An increasing problem”, 1998; Hughes et al, 2013), but it seems that contamination is limited to areas around human activity, both past and present (Convey, 2015**;** Clout & De Poorter, 2008). Broady and Smith (1994), in their analysis of algae imported into the Ross Sea region via boots and soil attached to vegetables, identified fifty taxa with the potential to colonise the continent. However, they also found little evidence for these species spreading from the immediate vicinity of Scott Base.

These studies strongly indicate that alien microbes are capable of long term survival in these harsh conditions, but also suggests that they may not be as mobile as many (Convey, 2011) have thought likely. Indeed, it seems that Antarctic microbial life is very well differentiated and even nearby areas may host distinct microbial communities. This is, from a conservation point of view, both a good and a bad feature; it suggests that perhaps even invasive microbiota may be very locally confined, but also implies that there may be a very large number of habitats which need to be protected from each other.

Particular areas have attracted general concern such as potential contamination of Lake Vostok through drilling (Frenot et al, 2005), but most scientists seem to regard the microbial contamination of the continent to be inevitable because of the extreme difficulty in preventing it. This is a highly under-researched area (as noted by Convey, 2011 and 2015), and one for which much greater knowledge will be needed before its risks and mitigation measures can be usefully discussed.

In the meantime, the suggestion that areas (ASPAs) be set aside in which contamination can be kept to a minimum (Hughes et al, 2013) would seem to be a sensible measure for New Zealand to support. More research should also be carried out regarding the extent and degree of algal contamination around Scott Base going forward. Consideration should also be given to the risks surrounding intra-Antarctic contamination, and to whether existing procedure are adequate.

5.2 Diseases

This report has dealt with the risks of disease transfer, from human to animal, via foods and sewage. However, there remain a number of other risks, not least of which is the potential for disease to pass directly from animals to humans. While handling of wild animals has been identified as a risk to be avoided where possible (Potter, 2006), it is not known what procedures are in place should a researcher show signs of a potentially zoonotic illness after working closely with Antarctic wildlife.

5.3 Invertebrates

Many of the invertebrate organisms in Antarctica live in soil, and little is known about their diversity, nor about the extent of spread of alien populations (Convey, 2011). More information is needed regarding the extent of invasion of these species, both within and outside research stations. Various species of nematodes, dipterans and micro arthropods were imported to Rothera Station on an uncleaned construction vehicle (Hughes et al, 2010a), fortunately identified and removed before they could contaminate the base area. However, alien earthworms, mites and fly larvae were found in discarded soil at the Schirmayer Oasis (“Introduction of non-native species in the Antarctic Treaty Area: An increasing problem”, 1998). Alien springtails have already been noted on the South Shetland Islands, Adelaide Island and Deception Island (Convey, 2015), while alien nematodes have been found on Possession, Kerguelen and Macquarie Islands (Frenot et al, 2005), and even three species of alien slugs on the Kerguelen, Macquarie and Marion Islands (Frenot et al, 2005).

The potential for effective response for alien invertebrates found outside bases is currently very limited. The information paper, “Introduction of non-native species in the Antarctic Treaty Area: An increasing problem” says, ”If alien organisms manage to establish themselves in the Antarctic, removal will only be possible very locally and only for the larger, visible organisms, like grasses and maybe invertebrates if the medium they are living in can be removed.” (“Introduction of non-native species in the Antarctic Treaty Area: An increasing problem”, 1998)

The task of keeping alien microorganisms of all kinds out of the continent has been described as “impossible” (Hughes & Convey, 2010). Therefore, until adequate knowledge is known about this group of species, and until specific targets for prevention and eradication have been identified, it is probably impractical to recommend that Scott Base to carry out any additional procedures regarding this group of species beyond what has already been discussed in this report.

5.4 Intra-Antarctic Contamination

Contamination within the Antarctic region is increasingly being regarded as at least as significant as preventing invasions from outside the continent (Convey, 2011). Fifteen distinct regions within the continent have so far been identified (Convey, 2015). Ross Island sits just off the mainland adjacent to the South Victoria Land bioregion, with the Transantarctic Mountain region and North Victoria Land regions nearby and the Marie Byrd Land region across the Ross Sea ("Study Identifies Biogeographic Regions in Antarctica", 2012). Projects such as monitoring the penguin colonies at Cape Adair are already known to be supported from Scott Base.

As Scott Base increasingly supports more distant research projects, it will also have to deal with intra-Antarctic contamination issues. Antarctic species transported across these boundaries are expected to have inherent advantages for colonisation, being already adapted to the harsh Antarctic climate (Convey, 2015), and some species may well become invasive when transported between different continental environments. Hughes and Convey (2010) identify even smaller regions, such as ranges or individual nunataks as possessing biologically isolated and therefore supporting diverse species. Furthermore, as more of these biologically distinct areas are identified, the greater will be the costs and inconvenience associated with preventing contamination among them (Hughes & Convey, 2010). Potter (2006) identifies the lack of suitable quarantine procedures for air transport as a key area to be developed, including, for example, decontamination of the landing skids of helicopters such as those used as Scott Base.

At the most local level, that of individual nunataks, species contamination may be occurring at a significant rate even within Ross Island. Mitigation measures to limit this might, for example necessitate boot change or cleaning between visits to individual nunataks, or possibly even smaller scales. This is unlikely to be a popular measure, and more research is required to ascertain whether it is necessary.

6.0 Conclusion

The development of adequate biosecurity policies in the region is hampered by the slow nature of the Antarctic Treaty system, the lack of co-ordination between the signatory countries, and particularly by the lack of knowledge of Antarctic biota, most particularly at the microscopic level. There is also the difficult human problem, when introducing new precautionary procedures, of persuading people that these new procedures are necessary. New Zealand has already done much to implement many of the recommendations made by Ranjith et al (2012) and others. New Zealand may therefore be reaching the limit of 'easy wins', changes which can be made in this area without adjustment of the attitudes, practices and expectations of those who work on and in conjunction with Scott Base.

Biosecurity within the region has already seen a dramatic shift away from the soil transportation experiments of the 1950s-1970s as described by Convey (2015), towards increasingly stringent quarantine procedures and the rather less comprehensive monitoring and response policies that are now emerging. It is expected that the trend will continue in the foreseeable future as more information becomes available regarding the diversity of life on the Antarctic continent, and the effects of alien species within this area, the wider Antarctic and beyond. In addition, the emergence of legal liability for biological contamination of the continent is a salutary reminder that nations may, in the future, face penalties for breaches. Nevertheless, since the only possible way to prevent contaminations occurring at the bacterial level would require withdraw from the continent altogether (Convey, 2015), some balance must be found to minimise the contamination caused by human use of the continent as this use expands. It is hoped that the recommendations made in this report are of use to this discussion.

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8.0 Appendix: Summary of Recommendations

2.2 Clothing and Personal Items

Antarctica New Zealand should not, when preparing passengers for departure, require that the bags be set out on the central grassed area of the Antarctic Centre for labelling

Secondly, that travellers be required to fill out departure cards regarding their movements over a suitable timeframe prior to travel and declare whether they have had contact with farm animals or visited wilderness areas while abroad.

Thirdly, checks should be carried out on the footwear of outbound passengers; it may be valuable to extend this to include the hems of trousers as well.

Spot-checks should be carried out on leavers

A bio-security dog could be used to search for contaminated clothing.

Travellers should be required to declare any foodstuffs carried and declare that these are in a clean and/or sealed state. Fruit should be visually inspected to ensure that it is free from visible soil or mould contamination.

2.3 Food

The feasibility of supplying irradiated foods, particularly fruit and vegetables, be periodically reviewed.

Consideration is required whether uncooked meat, whether chilled or frozen, and freeze-dried meat should cease to be supplied to field camps in light of the risks of meat-borne diseases

2.4 Business Process Review

A full business processes review should be carried out on departure procedures and those relating to cleaning of used clothing and equipment on return.

3.2 Recent Progress in International Monitoring Measures

New Zealand should consider setting up a database of invertebrates discovered in and en route to Antarctica, similar to that maintained by the Australian Antarctic Division.

3.3 Flies and other Invertebrates

Insect traps should be installed in the sleeping quarters at Scott Base

Insect traps should be installed in and around containers and outbuildings

Investigation could be made into the feasibility of DNA analysis of alien specimens at Scott Base

3.4 Plants

The Scott Base area should be periodically inspected for alien plants, particularly areas around the building perimeter, containers and outbuildings, where plants might establish

Periodic monitoring with binoculars could be made of high risk, frequently visited ice free areas outside the base, such as Crater Hill and the cliffs outside Scott Base.

3.5 Waste

Investigation should be made of all known historic camps which may contain rubbish dumps and latrines, and an assessment made of the contamination risk.

More research is required on the risk of disease transfer through the sewage system

3.6 Biosecurity Officer

It is recommended that a fulltime biosecurity officer post be created.

The biosecurity officer should investigate the plant seen in Square Frame Hut

3.6 Reporting System Improvement

The base's incident reporting system should be reviewed. Measures to make it more user-friendly for visitors include paper forms, perhaps issued on arrival.

Long-term base staff should ensure the reporting of all incidents that they hear about

Reporting instructions should be prominently displayed on A1 posters around the base.

3.7 Risk-Based Monitoring

The enhanced risk of combining winter hydroponics with monthly winter flights and fresh food imports requires reassessment.

The increased risk due to ongoing major construction work will need to be assessed and additional monitoring put in place around this area

4.2 Planning an Effective Response Strategy

New Zealand should participate in a workshop with other nations to arrive at a common response plan or, if this is not possible, hold these discussions internally.

A number of scenarios relating to known invasive species should be worked through and planned for.

4.3 Specific Key Issues Identified

Guidance protocols are required to assist plant species identification, and timescales and methods for eradication, especially for discoveries made in remote areas.

Instructions for the capture and killing of animal aliens are also required

Guidance is required on whether naturally transported aliens should be treated separately to those brought in by humans.

Guidance is required on the acceptability of herbicides and pesticides.

Consideration is required as to the identification of species invasions which have progressed too far to be effectively treated, before extensive damage is caused in the attempt.

Scott Base should prominently display its response guidance to staff on A1 posters around the base.

4.4 Other Considerations

A failure analysis should be carried out on the Casey fly invasion to identify the point where it became untreatable

Interviews should, if possible, be held with base leaders who have declined to carry out eradications of invasive species to understand their motives

4.5 Other International Contributions that New Zealand Might Make

New Zealand could advocate for the updating of the Environmental protocol to explicitly cover unintentional introductions, and to cover intra-Antarctic species introductions

New Zealand could also advocate for the creation of a central fund for environmental projects such as eradications

5 Limitations of the Above Recommendations

Further research is required in all fields, but particularly those relating to microbial contamination, transmittable diseases, invertebrates (particularly soil invertebrates) and preventing intra-Antarctic contamination, both between bioregions and on smaller scales.

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